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for
Laser Initiated Ordnance System Validation Program

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1.0 SCOPE

1.1 Scope. This report summarizes the efforts and results of the Laser Initiated Ordnance System Validation Program (LIOSVP) contract number NCCW-0032.

(X1) 1.1.1 Acknowledgements. This program was possible through the support of the NASA Office of Safety and Mission Assurance, NASA Office of the Chief Engineer, NASA Office of Space Access and Technology, NASA Goddard Space Flight Center Wallops Flight Facility, and the NASA/DoD/DoE/Industry Laser Ordnance Team (see Table I).

This program was funded by NASA Headquarters as a pathfinder contract approach: "NASA Cooperative Agreement with Industry". The objective is to more quickly and efficiently implement programs having general beneficial interest in the US industry. Under the terms of the cooperative agreement NASA and the Ensign-Bickford Company, as the industry partner, each brought resources to the two programs completed under this contract to accomplish that general benefit. Only a small funding level of $415,000 was required. The funding was provided by the Engineering and Quality Management Office, Dr. Daniel Mulville, Director, in the Office of Safety and Mission Assurance, Mr. Frederich Gregory, Associate Administrator. The program was managed by Mr. Norman R. Schulze, Program Manager for Applied Technologies and the NASA Aerospace Pyrotechnic Systems Program Manager. The Launch Vehicles Office in the Office of Space Science also supported the program with funding. For the Nike-Orion mission, the NASA Goddard Space Flight Center's Wallops Flight Facility provided the launch vehicle, environmental testing facilities, payloads support for the laser experiment, and launch operations. For the Pegasus® mission, the Orbital Sciences Corporation provided integration support, environmental testing facilities, installation support, telemetry reduction, and the opportunity to fly aboard their launch vehicle. Specialty disciplines were provided by the ad hoc government-industry team, the "NASA/DoD/DoE/Industry Laser Ordnance Team," as were the various analyses conducted by team members. The Goddard Space Flight Center facility hosted a Laser Ordnance Workshop just five weeks after completion of the Sounding Rocket Demonstration Program and three weeks after the Pegasus® Flight Demonstration Program which transitioned the results of the program nationally. The results were transitioned internationally at the 31st AIAA/ASME/SAE/ASEE Joint Propulsion Conference held in San Diego, CA on July 10-12, 1995.

1.2 Program Overview. The purpose of the LIOSVP program was to provide the first flight experience for laser diode initiated ordnance technology. The program was executed in two distinct phases. The first phase adapted a previously designed laser initiated ordnance system for use aboard the Pegasus® launch vehicle. The mission was designed to initiate two of the nine fin rockets used to steer Pegasus® during the last portion of the stage 1 motor burn. Phase I comprised the following tasks:

a) Design of the laser initiated ordnance system
b) Development of the qualification test requirements
c) Analysis of the design
d) Fabrication of the qualification and flight hardware

e) Qualification testing
f) Integration of the flight hardware aboard Pegasus®
g) Mission flight

Phase II of the program used the same ordnance system design and adapted it to be used for stage 1 motor ignition, stage 2 motor ignition, and flight termination of a Nike-Orion sounding rocket. Phase II comprised the following tasks:

h) Adaptation of the system to the Nike-Orion vehicle
i) Fabrication of the flight hardware
j) Qualification testing
k) Integration of the flight hardware onto the Nike-Orion
l) Mission flight

1.3 Program structure. This program was instrumented under a NASA co-operative agreement. A technical oversight group was created which assisted with the program. This group, listed in Table I, comprised members from government and industry.

(X1) 1.4 NASA co-operative agreement with industry. This contract was the first NASA cooperative agreement with industry. This contracting method, executed as a joint effort with mutual responsibilities, proved to be a very rapid and cost effective method of achieving the program goals.

1.5 Summary of results. Both the phase I and phase II missions were successfully completed with all mission objectives achieved. The system successfully completed qualification and ground test efforts for both missions. Telemetry and visual data was obtained for both missions documenting successful completion of all events.

2.0 SUMMARY OF PHASE I

2.1 Phase I Task Descriptions. The following paragraphs describe each major task of the program.

2.1.1 Laser initiated ordnance system design. The design of the laser initiated ordnance system was based on a system previously designed and tested under the NRL Advanced Release Techniques program. This design was presented in detail at the first Technical Interchange Meeting (TIM1). This presentation focussed on the internal safing circuitry of the Laser Diode Firing Unit (LDFU), electrical interfaces from the laser ordnance system to the Pegasus® avionics, and the ordnance interface to the Pegasus® fin rockets.

2.1.2 Qualification test requirements development. The qualification test requirements were developed during TIM1 and documented in the formal test plan (TPL10004/3). These requirements were revised during TIM2 and the test plan was updated.

2.1.3 Analysis of the design. Analysis of the design was provided by various members of the team. A list of the analyses performed follows:

Analysis	Author	Document
Bent pin analysis	EBCo	ERL10004/1 (see 2.3 for title)
System performance	EBCo	ERL10004/2 (see 2.3 for title)
Laser eye hazard	EBCo	ERL10004/3 (see 2.3 for title)
Mission Safety Assessment	OSC	Safety Assessment for Laser Initiated Ordnance System Validation Program
Safety Assessment Report	NASA JSC	Safety Analysis Report for Laser Diode Firing Unit, ETS and Detonator

In addition to the formal documented analyses, additional analyses were performed. The Aerospace Corporation performed a detailed circuit analysis and sneak circuit analysis which revealed two potential overstress conditions in the design. These circuit problems were corrected prior to fabrication.

2.1.4 Qualification and flight hardware fabrication. The following hardware was fabricated for qualification and flight:

Item	PN	Qty	Use
Laser Diode Firing Unit (LDFU)	L10004-1	2	1 flight, 1 qual
Energy Transfer System (ETS)	H10001-1	2	1 flight, 1 qual
Laser Initiated Detonator (LID)	235753-1	30	15 qual, 1 phase I ground test, 1 phase I flight, 3 phase II ground test, 3 phase II flight, 7 spare

Laser Initiated Squib (LIS)	235702-1	30	15 qual, 1 phase I ground test, 1 phase I flight, 13 spare
Manifold	F10098-1	7	3 transfer verification, 1 phase I ground test, 1 phase I flight, 2 spare
Pressure Bomb	F10096-1	3	1 flight, 1 qual, 1 spare

2.1.5 Qualification testing. The qualification testing was performed in accordance with the test plan (TPL10004/3) and the test procedure (TPL10004/4). One problem was encountered during qualification testing. During random vibration testing, the vibration table was unable to achieve the desired test level due to an uncontrollable table resonance. The system was successfully tested at a lower than specified level. The specified level was achieved during phase II qualification testing (see ERL10004/5 for a complete description). Aside from this problem, all qualification testing was successfully completed.

2.1.6 Flight hardware integration. The flight hardware (less the ordnance) was installed onto the aft skirt prior to mating the aft skirt to the vehicle. Following the aft skirt mate, the LDFU was tested as part of the normal flight simulation testing. During flight simulation testing, the Pegasus® avionics are "flown" by providing simulated flight dynamics data and the response of the avionics is monitored. During this testing, the ordnance firing circuits are connected to electrical pulse catchers which monitor the level and time of the ordnance firing circuit outputs. For the laser system, optical pulse catchers were designed and built which would provide the same information. These optical pulse catchers were used during each flight simulation test (the test is repeated at various points during the vehicle build). The optical pulse catchers were also used to assure that no transient laser pulses occurred during power switching (both on and off). All the vehicle integration tests were completed successfully.

Following the combined systems test, which occurs after the Pegasus® is mated to the L-1011 carrier vehicle, the ordnance was installed. The installation was made through the safe/arm access door with the Pegasus® located on the hot pad (a section of the taxiway adjacent to the air strip). This installation was performed about 24 hours prior to launch. The optical pulse catchers were used to perform a stray light test similar to a stray voltage test immediately prior to connection of the LID and LIS. Once the ordnance was installed, the safe/arm plug was installed and the experiment was ready for flight.

(X1) 2.1.7 Mission flight. The first launch attempt was scrubbed due to poor weather. A one day re-cycle was planned so the ordnance was left installed and the safe/arm plug was removed. The safe/arm plug was re-installed the next day just before take-off of the L-1011. The second launch attempt was scrubbed during captive carry prior to drop due to an insulation problem with the vehicle. After the L-1011 landed it was determined that the repair would take a few days so the LID and LIS were left installed but were disconnected from the ETS. Following the insulation repair, the LID and LIS were reconnected to the ETS about 24 hours prior to launch. The Pegasus® vehicle was successfully launched on April 3, 1995 from Vandenberg AFB. At T+5.0 seconds following release from the L-1011, the stage 1 motor was ignited. At T+67 seconds, the flight computer commanded the LDFU to fire the fin rockets. Successful fin rocket ignition was observed on the chase plane video and confirmed by the strain gage telemetry. The LDFU also successfully fired the LIS into the pressure bomb at T+79 seconds with the vehicle at 175,000 ft altitude travelling at 7500 ft/sec. The pressure bomb data was not immediately available (it was recorded for post mission playback) but was confirmed the following day. Following the squib initiation at T+79 seconds, the experiment was complete. The Pegasus® vehicle successfully completed its mission by placing three satellites into their proper orbits. A summary of the mission together with the flight data can be found in Flight Demonstration of Laser Diode Initiated Ordnance, AIAA 95-2982 by C. Boucher and N. Schulze.

2.2 Phase I meetings. The following meetings were held during phase I:

Meeting	Date	Location
TIM 1 (System Baseline Review)	10/20/93	NASA/GSFC/WFF
TIM 2 (Test Readiness Review)	1/5/94	NASA/GSFC/WFF
TIM 3 (Mid-Term Review)	5/11/94	Orbital Sciences Corp.
TIM 4	11/15/94	NASA/GSFC/WFF

2.3 Phase I documents. The following documents were created during phase I:

Number	Rev	Title/Description
ERL10004/1	X0	Pin Fault Analysis for LDFU PN L10004-1, this report documents a bent pin analysis for the laser diode firing unit.
ERL10004/2	-	LIOSVP System Performance Prediction Report, this report documents the predicted laser power at each point in the system over the operating environments and forms the basis for the acceptance criteria.
ERL10004/3	-	Nominal Ocular Hazard Distance Calculation for LDFU PN L10004-X, this report documents the laser eye safe distance calculations for the system.
ERL10004/5	-	LIOSVP Qualification Test Report, this report documents the results of the phase I and II qualification testing.
LDA20186/1	-	Interface Control Document For LIOSVP Flight Experiment, this document defines the interface requirements for the laser system.
MIH10001/1	-	Manufacturing Instruction for Energy Transfer System PN H10001, this document defines the processes and procedures used to manufacture the ETS.
MIL10003/1	-	Manufacturing Instruction for Internal Wire Harness PN L10003-1, this document defines the processes and procedures used to manufacture the internal wire harness.
MIL10004/1	-	Manufacturing Instruction for the Fabrication of LDFU PN L10004-1 and L10004-2, this document defines the processes and procedures used to manufacture the LDFU.

TPL10001/1	-	Test Procedure for Safe/Arm Controller PWB Assembly PN L10001, this document defines the acceptance test procedure for the safe/arm controller PWB.
TPL10002/1	-	Test Procedure for Laser Driver PWB Assembly PN L10002, this document defines the acceptance test procedure for the laser driver PWB.
TPL10004/1	-	Acceptance Test Procedure for LDFU PN L10004-1, this document defines the acceptance test procedure for the LDFU.
TPL10004/3	A	Qualification Test Plan for LIOSVP, this document defines the qualification requirements for the system.
TPL10004/4	-	Qualification Test Procedure for LIOSVP, this document defines the qualification test procedure for the system.

2.4 Phase I drawings. The following drawings were created during phase I:

Number	Rev	Title
A40008	-	Schematic, Laser Ordnance Test, Orbcomm™
A50129	-	Electrical ICD, Laser Ordnance Test, Pegasus® M17
F10048	-	Chassis, Laser Firing Unit
F10049	-	Cover, Laser Firing Unit
F10094	-	Pressure Bomb Base
F10095	X0	Pressure Bomb Cap
F10096	-	Pressure Bomb Assembly
F10097	A	Manifold, Three Port
F10098	-	Manifold Assembly
H10001	-	ETS Assembly
L10001	A	Safe/Arm Controller Assembly
ELL10001/1	A	Electrical Schematic, Safe/Arm Controller
DLL10001/1	-	Master Pattern, Safe/Arm Controller Assembly
PLL10001/1	A	Parts List, Safe/Arm Controller Assembly
L10002	-	Laser Driver Assembly
ELL10002/1	-	Electrical Schematic, Laser Driver
DLL10002/1	-	Master Pattern, Laser Driver Assembly
PLL10002/1	-	Parts List, Laser Driver Assembly (two output)
L10003	-	Internal Wire Harness
L10004	-	Laser Diode Firing Unit Assembly
800851	A	ST Coupler Bracket

2.5 Phase I test equipment. A portable laser pulse catcher PN L10007-1 (power meter) for use on a flight line was designed and two were fabricated for use during vehicle integration. These units provided a go/no-go measurement of power level and pulse width of the laser pulse as well as detection of stray optical power.

3.0 SUMMARY OF PHASE II

3.1 Phase II Task Descriptions.

3.1.1 Adaptation of the system to the Nike-Orion vehicle. A baseline system was presented in the proposal to NASA and reviewed at the first technical interchange meeting (TIM 1). During TIM 1, the baseline system was presented as well as the test plan which was formalized in document TPM10002/1.

3.1.2 Flight hardware fabrication. Due to a limited program scope and similarity to phase I, no unique qualification hardware was fabricated. Qualification testing was performed using the flight hardware. The following flight and test hardware was fabricated:

Item	PN	Qty	Use
Laser Diode Firing Unit (LDFU)	L10004-1	1	1 flight
Energy Transfer System (ETS)	H10001-1	1	1 flight
Laser Initiated Detonator (LID)	235753-1	-	see phase I
Laser Initiated Squib (LIS)	235702-1	-	see phase I
Manifold	F10098-1	6	3 system qual test, 3 flight
Flexible Confined Detonating Cord Assembly (FCDCA)	235223-X	8	2 system qual test, 2 flight, 2 LAT, 2 spare
Self-Separating FCDCA	235339-X	4	1 system qual test, 1 flight, 1 LAT, 1 spare
Ordnance Transmission Assembly (OTA)	200290-X	3*	1 system qual test, 1 flight 1 spare
Through Bulkhead Initiator (TBI)	D10063-1	5*	2 system qual, 2 flight, 1 spare
OTA Coupler	235126-1	2*	1 system qual, 1 flight
Destruct Charge	300027	2	1 system qual, 1 flight
Deck Plate	F10305-1	1	1 flight
Deck Plate	F10305-2	1	1 flight
Deck Plate	F10305-3	1	1 flight

* Items drawn from EBCo stock and not specifically fabricated for this program

3.1.3 Qualification testing. The qualification testing was performed in accordance with the test plan (TPM10002/1) and the test procedure (TPL10004/6). One problem was encountered during testing. During random vibration testing, the LDFU experienced a failure whereby it would not remain armed. The problem was traced to a bad solder joint (see ERL10004/4 for a complete description). The solder joint was repaired and the qualification testing was successfully completed (see ERL10004/5 for a complete qualification test report). Qualification testing included a major ground test which verified the system performance in a configuration which modelled flight conditions as close a possible. This test was completed successfully (see ERM10002/4 for a complete description of the testing and results).

3.1.4 Design analysis. Since the system was used to initiate category A ordnance events, a significant amount of analysis was required to assure a safe system. In addition to the analyses performed during phase I, ordnance safety data was provided (ERM10002/1), a potential failure analysis was performed (ERM10002/2), and justification for the use of hot batteries (ERM10002/3) was provided.

3.1.5 Flight hardware integration. The flight hardware was integrated onto the vehicle two days prior to launch and countdown dry runs were performed. The hardware installation was performed in accordance with the payload manufacturing instruction (MIM10002/1).

(X1) 3.1.6 Mission flight. The mission was launched from pad 2 at NASA Wallops Flight Facility. The countdown began at 9:00AM on March 15, 1995 with a four hour countdown and a 1:00PM launch planned. At T-10 minutes the countdown was held due to inadequate visibility at the launch pad. Following a two hour hold the mission was successfully launched. Stage 1 ignition, stage 2 ignition, and stage 2 destruct all occurred as planned. Visual and telemetry data obtained during the flight documented a successful mission. A summary of the mission together with the flight data can be found in Flight Demonstration of Flight Termination System and Solid Rocket Motor Ignition Using Semiconductor Laser Initiated Ordnance, AIAA 95-2980 by N. Schulze, C. Boucher, and B. Maxfield.

3.2 Phase II meetings. The following meetings were held during phase II:

Meeting	Date	Location
TIM 1 (System Baseline Review)	8/30/94	NASA/GSFC/WFF
TIM 2 (Test Readiness Review)	11/14/94	NASA/GSFC/WFF
TIM 3 (Mission Readiness Review)	3/7/95	NASA/GSFC/WFF

3.3 Phase II documents. The following documents were created during phase II:

Number	Rev	Title/Description
ERL10004/4	-	Failure Report for LDFU PN L10004-1 SN 003, this report documents the failure investigation and corrective action for the bad solder joint discovered during vibration testing.
ERL10002/4	-	LIOSVP Qualification Test Report, this report documents the results of the phase I and II qualification testing.
ERM10002/1	X1	Safety Data for the Sounding Rocket Laser Initiated Flight Termination-Pyrotechnic Sequencing Program, this report documents safety data for the system.
ERM10002/2	X0	Potential Failure Analysis for the Sounding Rocket Laser Initiated Flight Termination - Pyrotechnic Sequencing Program, this report documents a potential failure analysis for the entire payload system.

ERM10002/3	X0	Safety Justification For The Use of Hot Batteries on Category A Events for the Sounding Rocket Laser Initiated Flight Termination - Pyrotechnic Sequencing Program, this report provides a justification for the use of charged batteries for category A ordnance events.
ERM10002/4	X0	Ground Test Report for the Laser Initiated Ordnance Sounding Rocket Destruct System, this report documents the system ground test results.
MIM10002/1	X0	Manufacturing Instruction for Fabrication of the Sounding Rocket Ordnance System, this document defines the processes and procedures used to manufacture, integrate, and test the payload.
TPL10004/6	-	Qualification Test Procedure for Sounding Rocket Laser Initiated Ordnance Flight Termination - Pyrotechnic Sequencing Initiation Demonstration Program, this document defines the qualification requirements for the system.
TPM10002/1	-	Qualification Test Plan for Sounding Rocket Laser Initiated Ordnance Flight Termination - Pyrotechnic Sequencing Initiation Demonstration Program, this document defines the qualification test procedures for the system.

3.4 Phase II drawings. The following drawings were created during phase II:

Number	Rev	Title
M10002	X0	Sound Rocket Destruct System Payload
ELM10002/1	X0	Electrical Schematic, Sounding Rocket Payload
F10305	X0	Deck Plate

3.5 Phase II test equipment. A launch control console and a remote control box used for stage 1 control were fabricated for this launch. These items are documented on the system schematic ELM10002/1.

(X1) 4.0 CONCLUSIONS AND RECOMMENDATIONS

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4.1 Conclusions. The successful completion of this program has demonstrated the following:

1) The laser initiated ordnance system designed and built for this program were successfully qualified and flown.

2) These flights demonstrated that solid state laser initiated ordnance technology is mature.

3) This program proved the principle of conducting operations without RF required during ordnance installations thereby demonstrating reduced operational efforts when laser initiated ordnance is used.

4) This program demonstrated viability of NASA's first use of a co-operative agreement with industry as an instrument to quickly and inexpensively demonstrate new technology.

5) The program demonstrated operational feasibility of head end thrust termination for solid propellant rocket motors as a good approach for a benign solid motor shutdown.

6) This program demonstrated that laser initiated ordnance can be effectively used for the most safety critical applications, namely flight termination and solid rocket motor ignition.

7) This program demonstrated that laser initiated ordnance technology can be safely used for both ground and flight ignition systems.

8) This program demonstrated that the sounding rocket is a cost effective method for demonstrating new technology.

9) Solid state laser diode ordnance initiation can be very inexpensively implemented.

10) The safety principles for solid state laser diode initiated ordnance that were employed in this program have been developed and implemented.

11) The viability of all solid state electronic safing for solid rocket motor ignition and flight termination has been demonstrated.

12) The NASA Headquarters government-industry team approach used herein proved effective in keeping program cost, schedule, and performance objectives maintained.

13) The approaches employed to quickly and efficiently transfer the technology to industry were very effective.

4.2 Recommendations. Based on successful completion of this program, the following recommendations are provided:

1) Laser initiated ordnance technology has been demonstrated in actual flight applications and should be considered for all new programs and program upgrades.

2) The co-operative agreement with industry should be used where a quick and cost effective program is a primary goal.

3) Early range safety involvement should be used as an effective method of mitigating program and schedule risk.

4) The government/industry team approach worked well and should be used where a diverse knowledge base would benefit a program.

5) This technology would benefit from a wider database which should be developed.

6) There would be a great benefit from a simple, dependable, safe, built-in test capability and a similar program is recommended for that technology.

(X1)

(X1)

Table I - NASA/DoD/DoE/Industry Laser Ordnance Team		
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13. ABSTRACT (*Maximum 200 words*)

A summary is provided for the work performed in a program initiated by NASA Headquarters to validate laser initiated ordnance in flight applications. The primary program goal was to provide the first flight experiences with this new laser diode initiated ordnance (LDIO) technology. The work was performed at the system level and was well documented, a list of the documents being provided. The program pioneered NASA's new way of doing business, referred to as the "NASA Cooperative Agreement with Profit Making Organizations." The contracting methodology was very successful in the accomplishment of program objectives. The program was conducted from design through qualification. In an unmanned commercial launch vehicle use, the Pegasus®, the Phase I program, LDIO initiated flight events and conducted a flight verification experiment. In Phase II it was launched as the payload to perform the initiation of critical hardware in a sounding rocket vehicle launch, the Nike-Orion. Here both stages were ignited using LDIO, one from the ground and the other by an in-flight system. LDIO was then used to demonstrate its capability to terminate thrust under the most severe flight conditions. The system featured all solid state safe and arm technology. Discussions include summaries of the program concept, contract implementation, team members, task descriptions, analyses, hardware, results, vehicle integration, safing, ordnance interfaces, and mission flight information. A summary of the analyses, the qualification test results, and the results of flight are included. The hardware was tested to the requirements of the Pegasus® launch vehicle and the Nike-Orion Sounding Rocket vehicle. It was integrated into Pegasus® by The Ensign-Bickford Company and Orbital Sciences Corporation. The Sounding Rocket program was integrated by The Ensign-Bickford Company and NASA Wallops Flight Facility staff. In both phases the operations aspect was an important objective. Principles claimed by the technology advocates have now been 100% successfully demonstrated as planned.

14. SUBJECT TERMS

Pyrotechnics, lasers, laser ordnance, reliability, safety, programs, solid rocket motors, applied technology, solid state safe and arm, Shuttle payload, unmanned launch vehicle system, sounding rocket, flight termination

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